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April 1, 2015

Ms. Michele Dermer
EPA Region 9, WTR-9
75 Hawthorne St.
San Francisco, CA 94105

Subject: Updated Evaluation of Annular Pressure-Temperature Relationship
PG&E Test Injection/Withdrawal Well 1
Permit No. R9UIC-CA5-FY13-1
King Island, San Joaquin County, California

Dear Ms. Dermer:

As required under Section D.6.b of Permit No. R9UIC-CA5-FY13-1 (the Permit), the annular fluid between the injection tubing string and casing of Test Injection/Withdrawal Well 1 is maintained near a target pressure of 100 pounds per square inch absolute pressure (psia) by injecting a nitrogen blanket in the uppermost portion of the annulus. The annular fluid pressure is known to be subject to fluctuation based on temperature variations resulting from changes in ambient conditions and the injection of oxygen-depleted air heated by the surface compression process. Section D.6.b further requires the monitoring of cyclical pressure-temperature changes within the well annulus during the first 30 days of operation, and Section D.6.c requires evaluation of the annular pressure-temperature relationship to assess the range of pressures that would be expected during normal operations and what changes might be indicative of a loss of mechanical integrity. That evaluation was submitted to EPA as an attachment to the February 2015 Monthly Report, submitted by PG&E on March 27, 2015.

PG&E's evaluation of the annular pressure-temperature relationship was based on the first 30 days of well operating data, which were collected prior to commencement of injection using the full compression train. About the time that the February 2015 Monthly Report was submitted, injection using the full injection train was initiated. As a result of the increased injection flow rates and temperatures, annular temperatures increased above previously evaluated levels, and the annular pressure increased above the previously predicted range of fluctuation of 30 to 140 psia. Specifically, the following annular and injection pressures and temperatures were measured:

Date	Time Range of Pressure Exceedance over 140 psia	Peak Annular Pressure and Time	Peak Annular Temperature and Time	Injection Manifold Pressure Range	Peak Injection Manifold Temperature
March 27, 2015	15:50 – 21:20	154 psia @ 18:00	95.3°F @ 16:07	1784 – 1786 psia	109°F
March 28, 2015	16:20 – 21:55	159 psia @ 18:45	94.0°F @ 17:33	1770 – 1790 psia	108°F
March 29, 2015	16:17 – 21:50	155 psia @ 18:40	96°F @ 17:30	1784 – 1785 psia	110°F
March 30, 2015	15:10 – 22:20	167 psia @ 17:55	95.8°F @ 16:54	1784 – 1800 psia	110°F

It was noted that the measured pressure increases were cyclical, peaking at roughly the same time each day, and were closely correlated with temperature. It was also noted that annular pressures returned to the previously predicted range as annular temperatures fell back into the range of the previously evaluated data. PG&E therefore concluded that the observed annular pressure increases were solely a reflection of the operating conditions and not related to a loss of mechanical integrity of the tubing string or casing. Nevertheless, because measured annular pressures had exceeded the previously predicted range, PG&E notified EPA orally at approximately 7:00 AM on Monday March 30, 2015 and followed up with more detailed information sent via email at 7:15 AM. At that time, we indicated we do not believe that the pressure spikes on the annulus are due to any downhole issue with the well, but rather due to the relatively high injection temperatures which increase the temperature of the fluid in the annulus. We indicated that an updated evaluation of the annular pressure-temperature relationship that incorporates the newly observed operating conditions would be submitted to EPA later in the week.

An updated evaluation of the annular pressure-temperature relationship for Test Injection/Withdrawal Well 1 is attached, and supports the above conclusions. An extended evaluation of the annular pressure-temperature relationship indicates that annular pressure becomes more sensitive to temperature changes as the temperature increases. Annular pressures are expected to remain between 30 and 600 psia during normal operating conditions. This is well below the maximum pressure applied during the internal mechanical integrity test performed on the well (2,500 psi), and is expected to change cyclically with diurnal temperature fluctuations. PG&E will continue to monitor the annular pressures and temperatures during injection operations in accordance with the permit requirements, and will report any fluctuations outside this range, or any unexpected pressure trends that do not correspond with the predicted annular pressure-temperature relationship, to EPA in accordance with Section D.6.b.

If you have any questions regarding this submittal or require additional information, please feel free to contact me at (415) 973-6270.

Sincerely,

Mike Medeiros
Manager, Renewable Energy Development

Cc: Mr. James Walker, EPA Consultant
Mr. Michael Woods, Division of Oil, Gas and Geothermal Resources
Ms. Anne L. Olson, Central Valley Regional Water Quality Control Board

Enclosures: (1) Evaluation of Tubing/Casing Annulus Pressure Excursions

EPA UIC Permit No. R9UIC-CA5-FY13-1

TUBING/CASING ANNULUS PRESSURE EXCURSIONS

An evaluation of the I/W Well 1 expected annular pressure changes was submitted with the February 2015 monthly report to EPA. These calculations, based on the initial 30 days of injection operations, predicted annular pressures to be in the range of 30 – 140 psia. This range was demonstrated to be consistent with thermal effects. Subsequently, annular pressures have been measured outside of this established range (154 – 167 psia). These excursions, reported to EPA Region 9 subsequent to their occurrence, were investigated as a potential loss of mechanical integrity. The investigation found these higher pressures are a result of increased gas injection rates and higher injected gas temperatures. They are consistent with thermal effects and there is no indication of a loss in wellbore mechanical integrity.

The observed variation in the I/W well annulus pressure and temperature since the start of injection operations (February 14, 2015) through March 30, 2015 is shown by **EXHIBIT 1**. The associated injection pressures and rates are given in **EXHIBIT 2**. The annulus pressure began to exceed the expected cyclic range of annulus pressure fluctuations on Friday, March 27, 2015 peaking at 154 psia. The pressure decreased to less than 90 psia before increasing again to 159 psia the next evening. The annulus pressure continued to cycle between 80 and 160 psia during the next two days in sync with the changing annulus temperatures.

In review, the methodology used to predict the change in the annulus pressure is based on the thermal expansion, or contraction, of the confined annular fluid (KCL water). The change in density as a function of the water temperature causes a change in the water volume in the annulus, increasing or decreasing the volume and pressure of the nitrogen cap. The temperature-pressure relationship developed based on the first month of normal injection operations is shown graphically by **EXHIBIT 3.** This relationship was calculated for an initial nitrogen blanket of 0.6 cubic feet at 100 psi on top of 214 barrels of annular fluid.

To investigate the higher pressure excursions, the temperature-pressure relationship for the annulus was extended for water temperature changes greater than +0.25 deg. Celsius (see **EXHIBIT 4**). Higher wellbore temperatures are expected due to increased gas injection rates and higher injected gas temperatures.

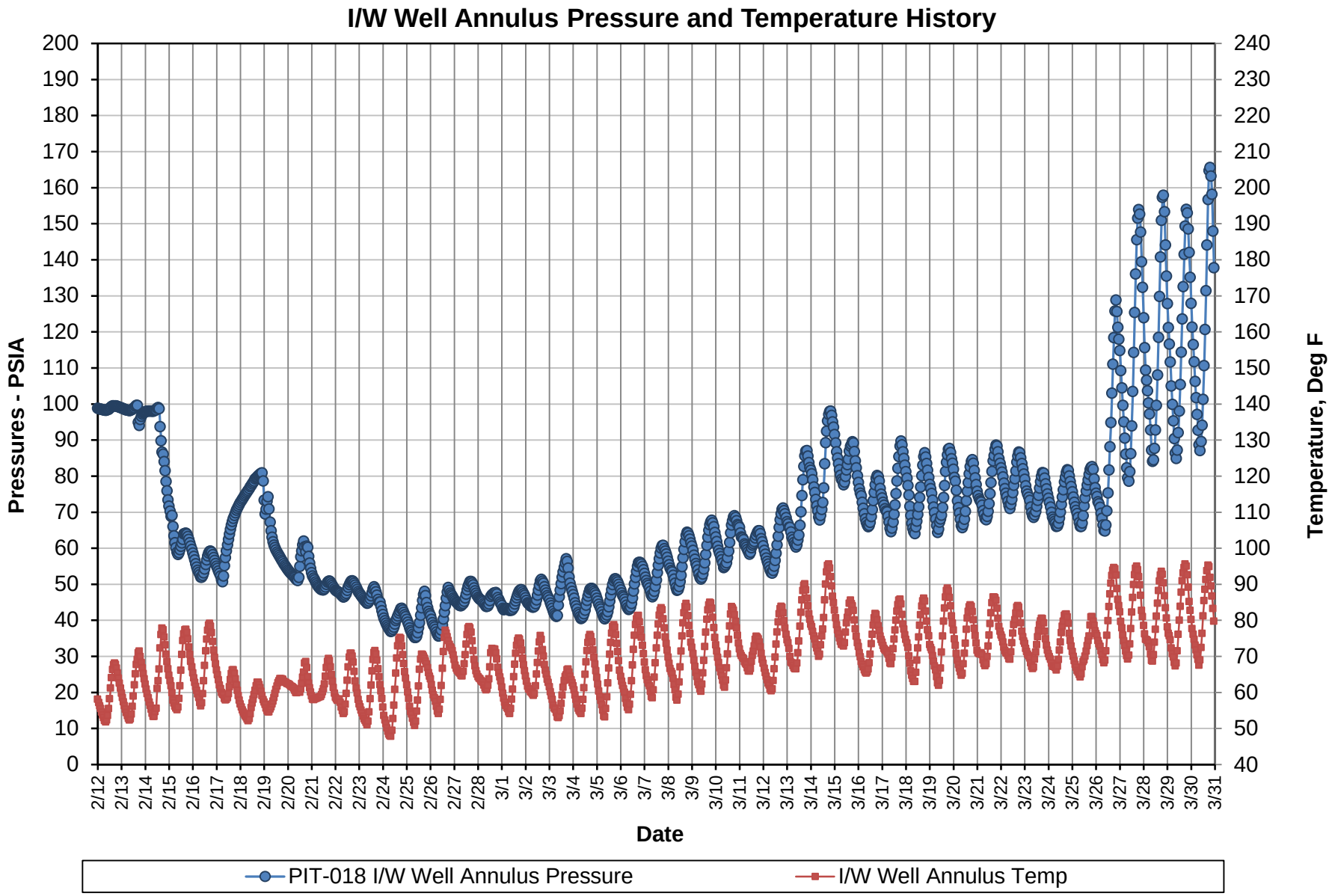
The temperature difference being evaluated in **EXHIBIT 4** is the difference between an initial T_i and an operating T_f wellbore temperature. The initial average wellbore temperature (T_i) prior to injection is 94.0 deg. F. (average of 60.0 deg. F. surface and 128.0 deg. F. bottomhole). The operating average wellbore temperatures (T_f) are calculated as a simple arithmetic average of the surface wellbore temperature and the bottomhole wellbore temperature. The bottomhole temperature is measured continuously by a surface readout gauge. The surface wellbore temperature, which is not being measured directly, is largely determined as a moving average of the variation in the measured annulus temperatures (less a few degrees for heat losses). The temperature profiles are presented by **EXHIBIT 5**.

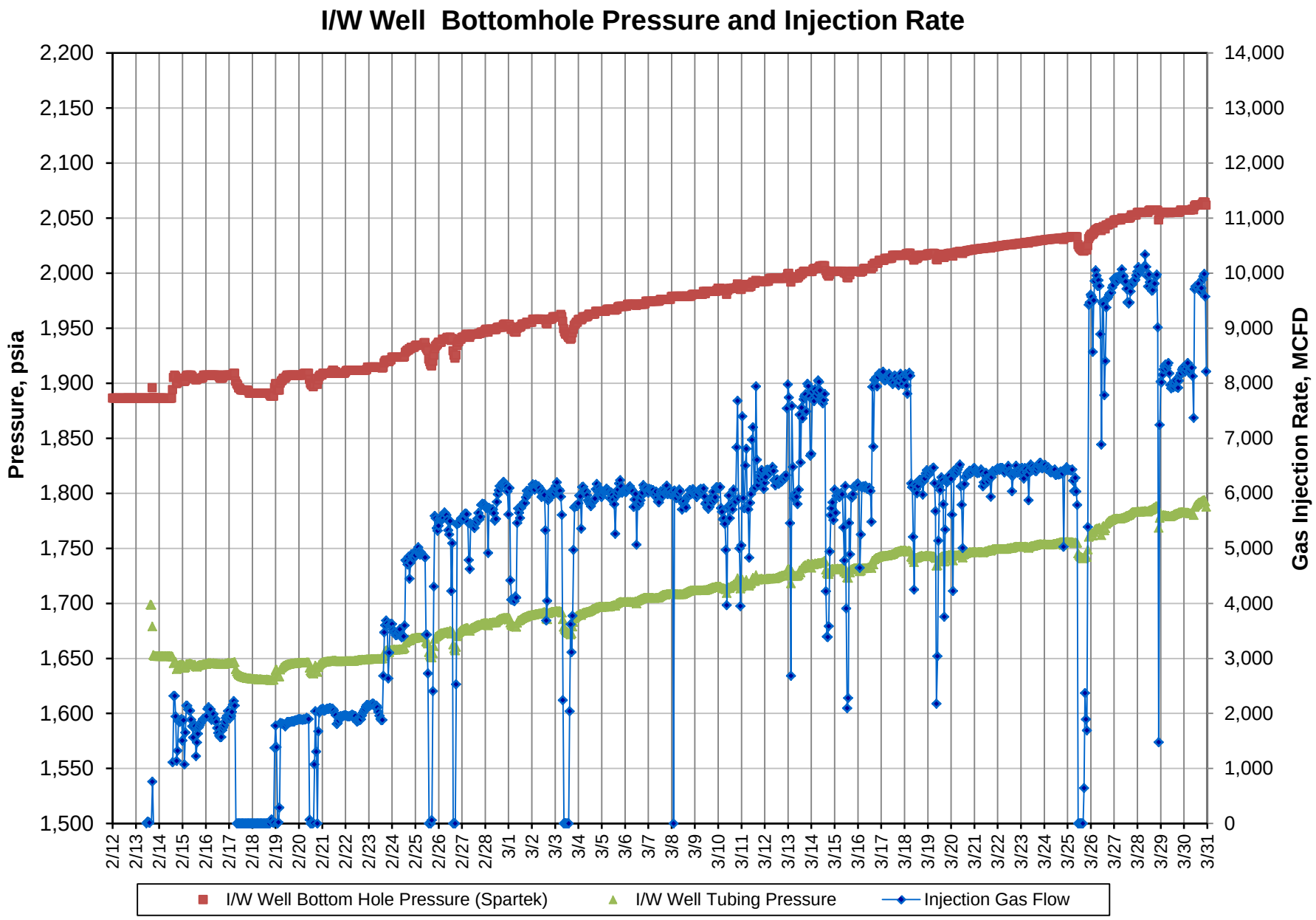
Based on the first month of injection operations, the pressure-relationship was only evaluated for water temperature changes between 0.0 and -4.0 deg. Celsius (**EXHIBIT 5**). However, the recent pressure excursions above 140 psia have occurred as a result of annulus water temperature changes greater than 0.50 deg. Celsius.

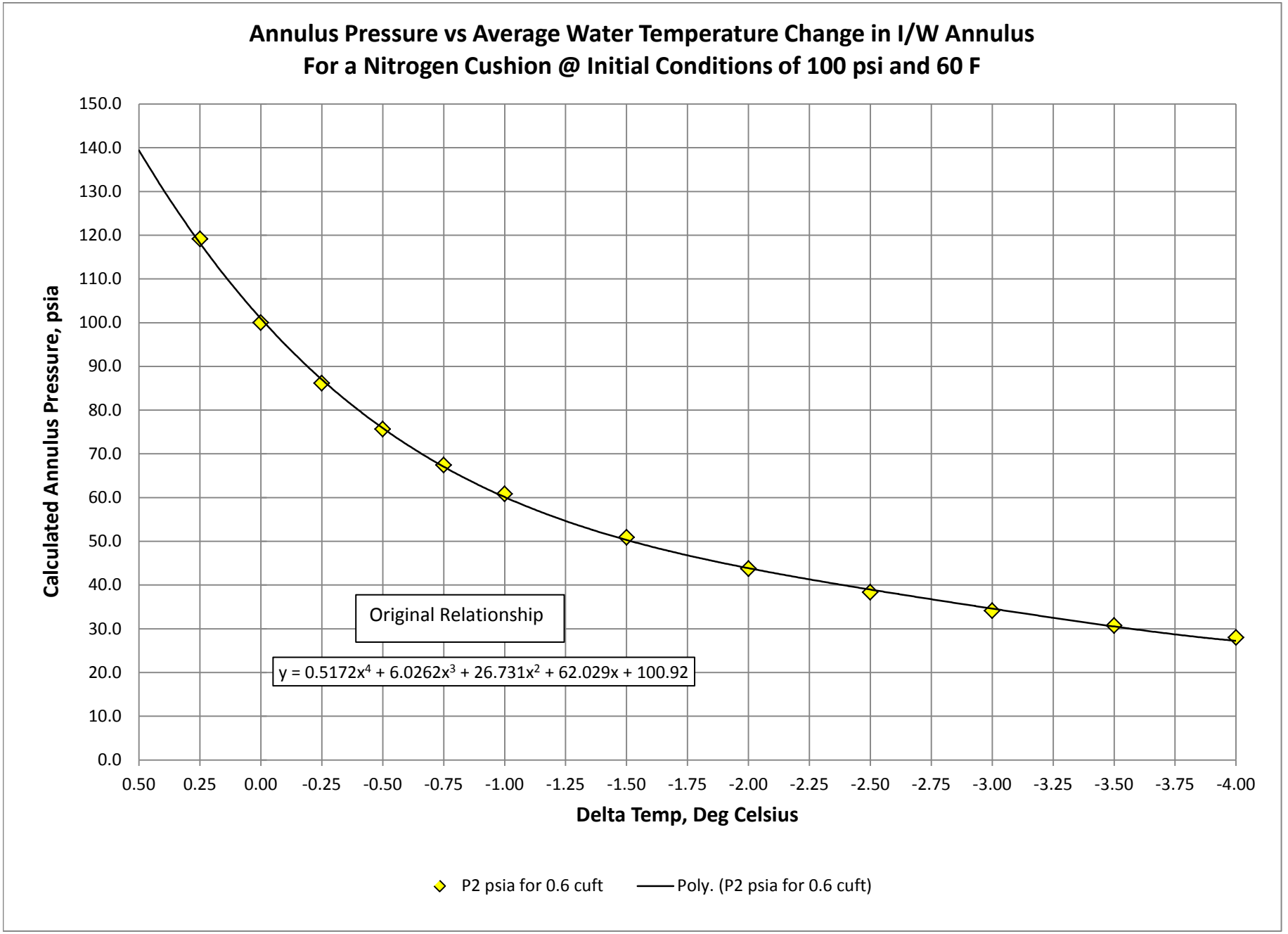
The extended pressure-temperature relationship shows that the annulus pressure begins to increase exponentially for changes in water temperature greater than +0.25 degree Celsius. This explains the larger excursions in annulus pressures since Friday March 27 because the annulus temperatures have increased due to the higher injection rates and temperatures. Using the extended pressure-temperature relationship, the annulus pressures are calculated and compared to the observed annulus pressures (through March 30) in **EXHIBIT 6**. There is reasonable agreement between the calculated and observed pressures for the range of water temperature changes investigated. Based on these results, it is concluded that the observed I/W well annulus pressures to-date can be attributed to thermal effects and not to any wellbore integrity issues. This is reinforced by the fact that the annulus temperatures and air injection temperatures are cycling in sync with the annulus pressures.

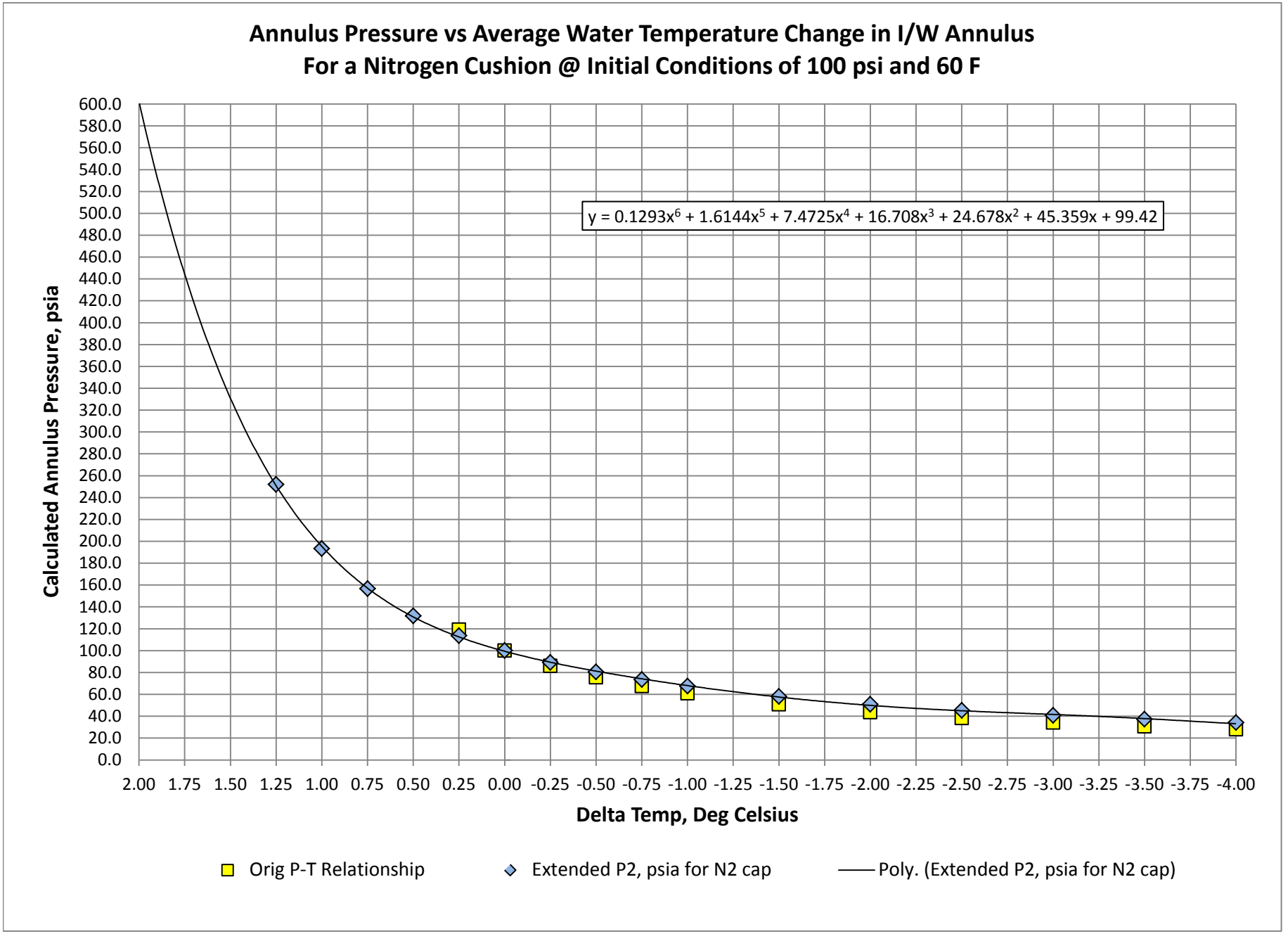
REVISED RANGE OF ANNULAR PRESSURES

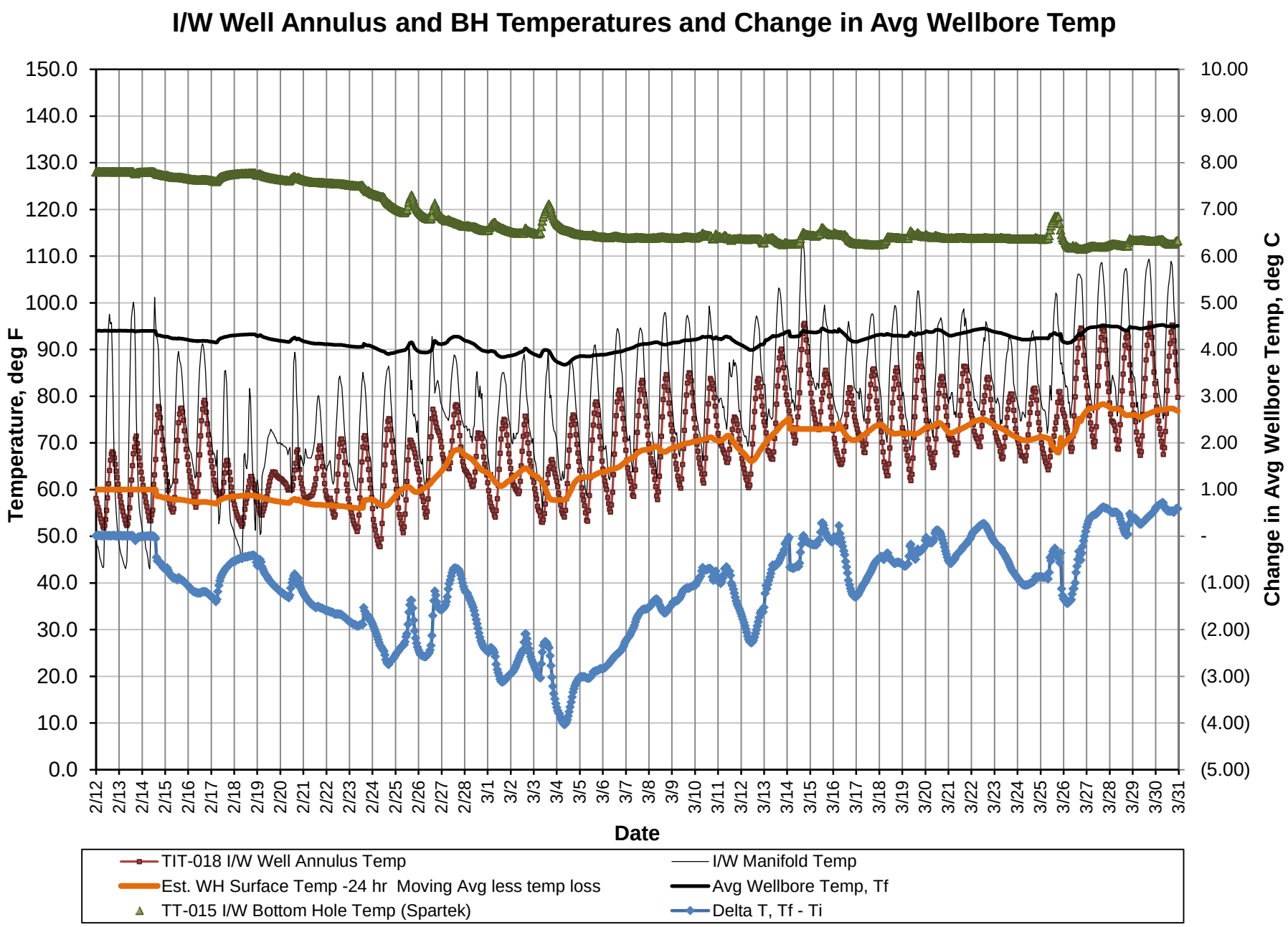
The revised expected cyclic range of I/W well annulus pressure fluctuations during injection operations is 30 – 600 psia. The upper range in annulus pressure is calculated for an average annulus water temperature (T_f) of 97.6 deg. F compared to the initial temperature of 94.0 deg. F. (delta temperature of +2.00 deg. Celsius on **EXHIBIT 4**). An annulus pressure measured outside of this pressure range (especially if the pressure fluctuation does not coincide with the annulus temperature fluctuation) may indicate a potential loss of mechanical integrity and will be reported to the EPA and reviewed by PG&E.

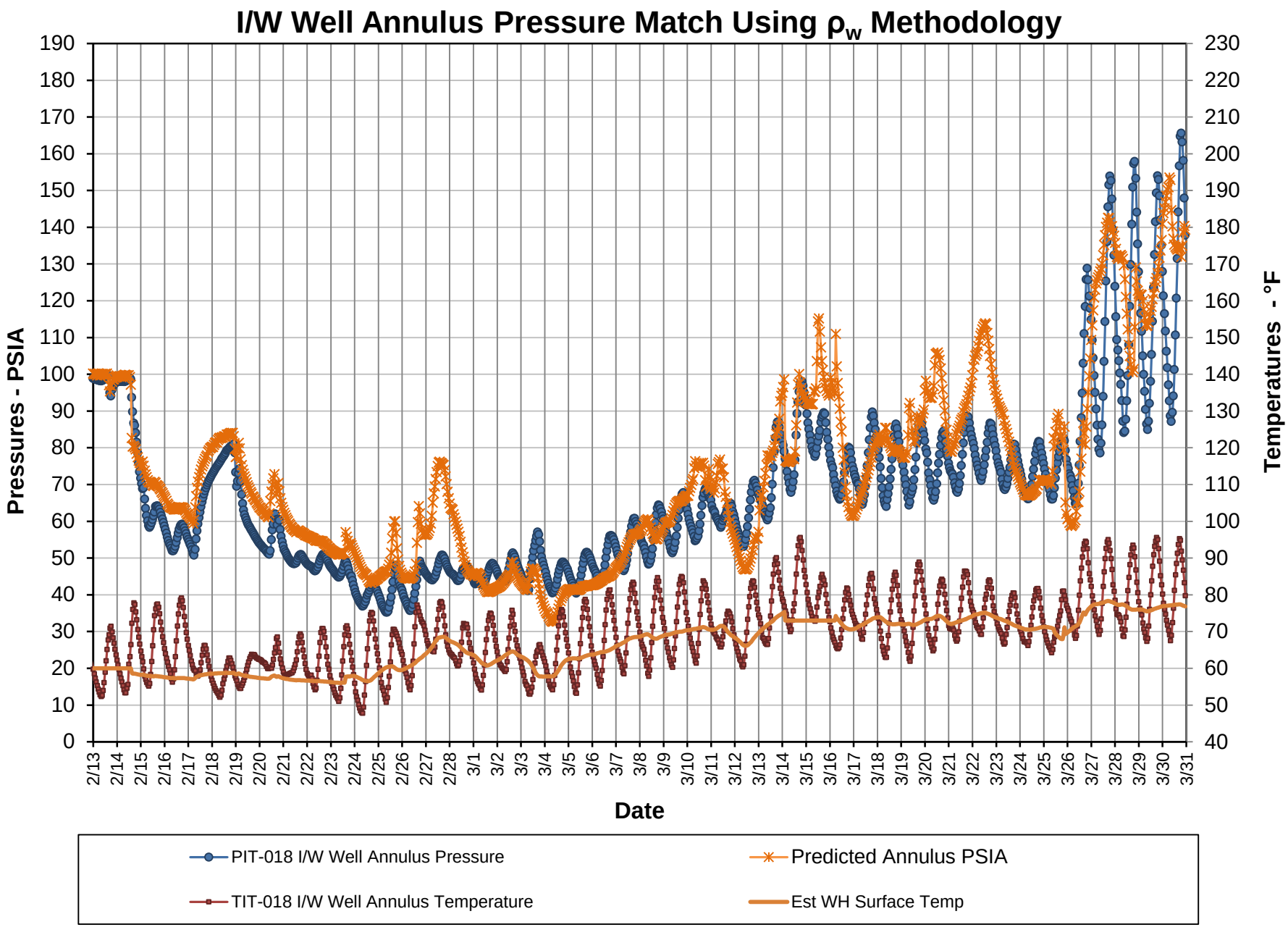

I/W Well Annulus Pressure and Temperature History
Pressures - PSIA
Temperature, Deg F
Date
PIT-018 I/W Well Annulus Pressure
I/W Well Annulus Temp


I/W Well Bottomhole Pressure and Injection Rate
Pressure, psia
Gas Injection Rate, MCFD
2,200
2,150
2,100
2,050
2,000
1,950
1,900
1,850
1,800
1,750
1,700
1,650
1,600
1,550
1,500
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
2/12 2/13 2/14 2/15 2/16 2/17 2/18 2/19 2/20 2/21 2/22 2/23 2/24 2/25 2/26 2/27 2/28 3/1 3/2 3/3 3/4 3/5 3/6 3/7 3/8 3/9 3/10 3/11 3/12 3/13 3/14 3/15 3/16 3/17 3/18 3/19 3/20 3/21 3/22 3/23 3/24 3/25 3/26 3/27 3/28 3/29 3/30 3/31
I/W Well Bottom Hole Pressure (Spartek)
I/W Well Tubing Pressure
Injection Gas Flow


Annulus Pressure vs Average Water Temperature Change in I/W Annulus
For a Nitrogen Cushion @ Initial Conditions of 100 psi and 60 F
Calculated Annulus Pressure, psia
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
-1.25
-1.50
-1.75
-2.00
-2.25
-2.50
-2.75
-3.00
-3.25
-3.50
-3.75
-4.00
Delta Temp, Deg Celsius
Original Relationship
y = 0.5172x4 + 6.0262x3 + 26.731x2 + 62.029x + 100.92
P2 psia for 0.6 cuft
Poly. (P2 psia for 0.6 cuft)


Annulus Pressure vs Average Water Temperature Change in I/W Annulus
For a Nitrogen Cushion @ Initial Conditions of 100 psi and 60 F
y = 0.1293x^6 + 1.6144x^5 + 7.4725x^4 + 16.708x^3 + 24.678x^2 + 45.359x + 99.42
Calculated Annulus Pressure, psia
600.0 580.0 560.0 540.0 520.0 500.0 480.0 460.0 440.0 420.0 400.0 380.0 360.0 340.0 320.0 300.0 280.0 260.0 240.0 220.0 200.0 180.0 160.0 140.0 120.0 100.0 80.0 60.0 40.0 20.0 0.0
2.00 1.75 1.50 1.25 1.00 0.75 0.50 0.25 0.00 -0.25 -0.50 -0.75 -1.00 -1.25 -1.50 -1.75 -2.00 -2.25 -2.50 -2.75 -3.00 -3.25 -3.50 -3.75 -4.00
Delta Temp, Deg Celsius
Orig P-T Relationship
Extended P2, psia for N2 cap
Poly. (Extended P2, psia for N2 cap)


I/W Well Annulus and BH Temperatures and Change in Avg Wellbore Temp
Temperature, deg F
Change in Avg Wellbore Temp, deg C
Date
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
-
(1.00)
(2.00)
(3.00)
(4.00)
(5.00)
2/12 2/13 2/14 2/15 2/16 2/17 2/18 2/19 2/20 2/21 2/22 2/23 2/24 2/25 2/26 2/27 2/28 3/1 3/2 3/3 3/4 3/5 3/6 3/7 3/8 3/9 3/10 3/11 3/12 3/13 3/14 3/15 3/16 3/17 3/18 3/19 3/20 3/21 3/22 3/23 3/24 3/25 3/26 3/27 3/28 3/29 3/30 3/31
TIT-018 I/W Well Annulus Temp
I/W Manifold Temp
Est. WH Surface Temp -24 hr Moving Avg less temp loss
Avg Wellbore Temp, Tf
TT-015 I/W Bottom Hole Temp (Spartek)
Delta T, Tf - Ti


I/W Well Annulus Pressure Match Using ρw Methodology
Pressures - PSIA
Temperatures - °F
Date
PIT-018 I/W Well Annulus Pressure
Predicted Annulus PSIA
TIT-018 I/W Well Annulus Temperature
Est WH Surface Temp